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RESEARCH MEMORANDUM

COMPONENT PERFORMANCE INVESTIGATION OF J71 EXPERIMENTAL TURBINE

I - OVER-ALL PERFORMANCE WITH 97-PERCENT-DESIGN STATOR AREAS

By Harold J. Schum and Elmer H. Davison

Lewis Flight Propulsion System
Cleveland, Ohio

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SUMMARY

The over-all component performance characteristics of a J71 experimental three-stage turbine with 97-percent-design stator areas were determined over a range of speed and pressure ratio at inlet-air conditions of approximately 35 inches of mercury absolute and 700° R.

The turbine brake internal efficiency at design operating conditions was 0.877; the maximum efficiency of 0.886 occurred at a pressure ratio of 4.0 at 120 percent of design equivalent rotor speed. In general, the turbine yielded a wide range of efficient operation, permitting flexibility in the choice of different modes of engine operation. Limiting blade loading of the third rotor was approached but not obtained over the range of conditions investigated herein. At the design operating point, the turbine equivalent weight flow was approximately 105 percent of design. Choking of the third-rotor blades occurred at design speed and an over-all pressure ratio of 4.2.

INTRODUCTION

The NACA Lewis laboratory has been conducting a general study of high-work-output low-speed multistage turbines. A previous experimental investigation of this type turbine was made on the J35-A-23 two-stage turbine (ref. 1). In that investigation, limiting blade loading occurred in the second-stage rotor, restricting the equivalent work to approximately 95 percent of the design value. At the maximum work output for the design equivalent speed, the turbine produced a brake internal efficiency of only 0.75. A subsequent study of the turbine design problems for this engine (ref. 2) indicated that, for various engine operating conditions, the turbine-outlet annular area becomes a critical design criterion. An outlet area that is too small results in a turbine limiting-loading condition. References 3 and 4, extensions of this study, indicate that, if the outlet

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area is increased much over that of the J35-A-23 two-stage turbine to avoid limiting loading, difficulty is encountered in designing a two-stage turbine within preestablished limitations of Mach number, turning, and static-pressure change.

Although it would be advantageous with respect to component weights to utilize a two-stage turbine, it is obvious from references 3 and 4 that the aforementioned aerodynamic design problems could be greatly simplified by including an additional turbine stage. Accordingly, the two-stage turbine of reference 1, which had a turbine-outlet annular area of 405 square inches, was modified to a three-stage unit having an outlet area of 469 3490
square inches. This three-stage configuration was then experimentally investigated (ref. 5) and was found to obtain the design work at the design equivalent speed with an efficiency of 0.83. The pressure ratio at which this design operating point was obtained, however, was greater than the design value of 3.5. Turbine limiting loading was closely approached and hence would restrict the possible modes of engine operation.

This turbine (ref. 5) would be suitable for operation with constant exhaust-nozzle area with reduced mechanical speed at cruise condition. However, if cruise operation at the design mechanical speed is required, this turbine would not be satisfactory, because the engine would operate with a considerably increased specific fuel consumption. With the latter mode of engine operation, the turbine would be in limiting loading and would not be capable of utilizing efficiently the pressure ratio imposed across it. In order to design a turbine so that the engine could cruise efficiently at a constant mechanical speed, a turbine-outlet annular area even larger than 469 square inches would be required. The cycle analysis presented in reference 4 suggests that a turbine-outlet annular area of approximately 550 square inches would keep the turbine out of limiting blade loading and permit efficient engine operation at constant mechanical speed over the range of flight conditions considered.

In order to obtain a turbine of conservative aerodynamic design that would permit more flexibility in the modes of engine operation that could be employed, a J71 experimental turbine was designed. This turbine was fabricated with three stages and differed from the J35-A-23 turbine (ref. 1) and the J71 three-stage turbine (ref. 5) in that the turbine-outlet annular area was increased to 550 square inches, as recommended in reference 4. The J71 experimental turbine was designed to utilize more air flow than the two reference turbines. Subsequent to design, however, and incorporated in the subject turbine, the stator areas were decreased to 97 percent of the original design values. The present report presents the over-all performance characteristics of this experimental turbine when operated at constant nominal values of inlet conditions of 35 inches of mercury absolute and 700° R. The unit was investigated over a range of speed from 20 to 130 percent of design equivalent speed and over a range of total-pressure ratio from 1.4 to 4.8. Over-all turbine performance results are presented herein in terms of brake internal efficiency and equivalent work (both based on observed torque measurements), equivalent total-pressure ratio, equivalent rotational speed, and equivalent air weight flow. Also presented herein are the results of interstage static-pressure measurements. Additional pertinent results are listed in table I.

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SYMBOLS

The following symbols are used in this report:

E	enthalpy drop based on torque measurements, Btu/lb
g	acceleration due to gravity, 32.174 ft/sec^2
N	rotational speed, rpm
p	pressure, in. Hg abs
p_x'	rating total pressure, static pressure plus velocity pressure corresponding to axial component of velocity, in. Hg abs
R	gas constant, 53.4 ft-lb/(lb)($^{\circ}$R)
T	temperature, $^{\circ}$R
w	weight flow, lb/sec
$\frac{wN}{60\delta}\varepsilon$	weight-flow parameter based on product of equivalent weight flow and equivalent rotor speed
γ	ratio of specific heats
δ	ratio of inlet-air pressure to NACA standard sea-level pressure, $p_0'/29.92$ in. Hg abs
ε	function of γ, $\frac{\gamma_{sl}}{\gamma_e}\left[\frac{\left(\frac{\gamma_e+1}{2}\right)^{\frac{\gamma_e}{\gamma_e-1}}}{\left(\frac{\gamma_{sl}+1}{2}\right)^{\frac{\gamma_{sl}}{\gamma_{sl}-1}}}\right]$

η_i brake internal efficiency, ratio of actual turbine work based on observed torque measurements to ideal turbine work based on inlet total pressure p_0' and outlet total pressure corrected for tangential velocity $p_{x,7}'$

θ_{cr} squared ratio of critical velocity to critical velocity at NACA standard sea-level temperature of 518.7° R, $\dfrac{\dfrac{2\gamma}{\gamma + 1} gRT_0'}{\dfrac{2\gamma_{sl}}{\gamma_{sl} + 1} gRT_{sl}}$ 3490

τ torque, ft-lb

Subscripts:

e engine operating conditions

sl NACA standard sea-level conditions

x axial (calculated)

0 turbine-inlet measuring station, in transition liner

1 turbine-inlet measuring station ahead of first stator

2 turbine measuring station downstream of first stator

3 turbine measuring station downstream of first rotor

4 turbine measuring station downstream of second stator

5 turbine measuring station downstream of second rotor

6 turbine measuring station downstream of third stator

7 turbine-outlet measuring station downstream of third rotor

8 turbine tailcone-outlet measuring station

Superscript:

' total or stagnation state

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APPARATUS

The experimental J71 turbine consists of three stages. The first two rotor stages are fully shrouded, while the third rotor stage is unshrouded. The turbine equivalent design conditions are as follows:

Work, Btu/lb	32.4
Weight flow, lb/sec	40.3
Rotational speed, rpm	3028
Inlet temperature, $^{\circ}R$	518.7
Inlet pressure, in. Hg abs	29.92

The method of deriving these equivalent design conditions is presented in reference 1.

The subject turbine was designed so that the first stage would produce 42 percent of the total work, the second stage 35 percent, and the third stage 23 percent. Subsequent to design, and incorporated into this experimental turbine, the stator flow areas were decreased to 97 percent of the original design areas. All blade profile sections had straight suction surfaces downstream of the throat, or minimum channel width. The turbine geometry differed from that of the original J71 three-stage unit (ref. 5) and its prototype, the two-stage turbine from the J35-A-23 turbojet engine (ref. 1), by the aforementioned rotor shrouding and by the increase in the turbine-outlet annular area to 550 square inches. This increase in area was acquired by diverging the turbine inner and outer shrouds. The turbine outer diameter at the entrance to the first stator was 33.5 inches; the corresponding inner diameter was 27 inches. There was a 5° divergence of the outer wall from the axis of the turbine rotor after the first rotor. A 12° convergence of the inner wall toward the axis prevailed after the first stator. This area change through the turbine can be noted on the schematic diagram of the turbine shown in figure 1.

A photograph of the over-all turbine experimental setup is shown in figure 2. The setup was essentially the same as that described in detail in references 1 and 5. Air was supplied by the laboratory combustion-air system at approximately 110 inches of mercury absolute and was metered by use of a submerged A.S.M.E. flat-plate orifice. The air was then throttled to the desired turbine-inlet pressure. A portion of this air was then ducted through two commercial jet-engine burners (see fig. 2), where it was burned. This heated air was then reintroduced into the main air supply. The air was then piped into a plenum chamber, through the turbine transition liners, through the turbine blading, and finally was discharged into the laboratory altitude exhaust facilities. By regulating the amount of fuel flow to the burners, the desired turbine-inlet temperature could be maintained. Screens were mounted in the plenum chamber to reduce air circumferential pressure variations. The pressure ratio across the unit was varied by butterfly throttle valves located in the exhaust ducting. Turbine power output was absorbed by two cradled electrical dynamometers of the eddy-current wet-gap type connected in tandem.

INSTRUMENTATION

Air-flow measurements were made with the standard A.S.M.E. orifice submerged in the 24-inch combustion-air supply line. The fuel flow to the burners was metered by rotameters in the fuel supply line, and the air flow to the turbine was corrected for this fuel addition. The turbine torque output was measured by means of a calibrated NACA balanced-diaphragm thrustmeter.

Measurements of temperature, total pressure, and static pressure were made in the axial locations indicated in figure 1. The turbine-inlet air state was measured at station 0. At the inlet measuring station, a combination Kiel-type total-pressure probe and spike-type thermocouple was located in each of the ten transition liners approximately 8 inches upstream of the first stator. The cross-sectional area of the transition liner at this measuring station is approximately circular. The thermocouples were immersed 1/3 of the passage depth, and the total-pressure tubes were immersed 2/3 of the passage depth. The arithmetic averages of the ten thermocouple and of the ten total-pressure-tube readings observed at these radial locations were considered representative of the average turbine-inlet temperature and pressure, respectively.

The turbine-outlet measuring station (station 7, fig. 1) was located approximately $1\frac{1}{2}$ inches downstream of the third-stage rotor and in the turbine tailcone proper. Provision for measuring total pressure, static pressure, and temperature were incorporated. Five Kiel-type total-pressure tubes were mounted at various circumferential locations and passage depths. Eight static taps on the outer radius of the passage and eight on the inner radius were also installed at various circumferential locations; the outer and inner taps were diametrically opposed. Four temperature rakes of five thermocouples each were fixed around the periphery of the tailcone at this measuring station. These consisted of duplicate sets of ten thermocouples, located radially at area centers of equal annular areas.

In addition to the inlet and outlet instrumentation, four static taps on the inner and outer shrouds were installed ahead of each row of blades and at the tailcone exit (see fig. 1). An exception was made at the entrance to the first stator (station 1), however, where two static taps, one on both the inner and outer walls, were installed behind each transition liner, making a total of 20 taps. The interstage static-pressure

taps were again spaced around the circumference of the turbine, the inner and outer taps being diametrically opposite. All static taps were located on the stator shrouds as near as possible to the center of two adjacent blades. During the investigation, the observed values of interstage static pressure at the outer shroud did not represent the true flow conditions near the tip. It is believed that leakage over the shrouded first and second rotor blading produced local flow effects which produced erroneous static-pressure readings. Consequently, these static-pressure values are
3490 not considered herein.

METHODS AND PROCEDURE

The turbine was operated at constant nominal values of inlet total pressure and temperature corresponding to 35 inches of mercury absolute and 700° R, respectively, for equivalent rotational speeds of 20, 40, 60, 70, 80, 90, 100, 110, 120, and 130 percent of design equivalent speed over a range of over-all total-pressure ratios $p_0'/p_{x,7}'$ from 1.4 to approximately 4.8. The inlet total pressure p_0' was taken as the arithmetical average of the ten Kiel-type probe readings located in the transition liners (measuring station 0, fig. 1). Turbine-inlet temperature was similarly determined at the same measuring station and corrected for recovery effects. The turbine-outlet pressure $p_{x,7}'$ is defined as the static pressure at the third-rotor outlet (station 7) plus the velocity pressure corresponding to the axial component of the absolute rotor-outlet velocity. This calculated value of $p_{x,7}'$ charged the turbine for the available energy of the rotor-outlet tangential velocity, and hence the efficiency values presented will be conservative. The pressure $p_{x,7}'$ was calculated from measured total pressure, static pressure, total temperature, air weight flow, and the known area at the measuring station.

A series of nominal over-all total-pressure ratios was imposed across the turbine, and at each selected pressure ratio the speed was varied from 20 to 130 percent of the design equivalent speed. At low speeds, however, the range of pressure ratio was limited by the high torque outputs, which exceeded the absorbing capacity of the dynamometers, making it impossible to maintain a constant speed. The inlet temperature was maintained constant by regulating the amount of fuel to the burners. Turbine-inlet pressure was fixed at approximately 35 inches of mercury absolute by regulating the butterfly throttle valves in the combustion-air inlet supply piping. Turbine work output and brake internal efficiency are based on the observed values of torque. Readings of torque and air weight flow were faired for each speed in order to minimize random experimental errors.

RESULTS AND DISCUSSION

Over-All Turbine Performance

The over-all performance of the J71 experimental turbine is presented in terms of equivalent shaft work, equivalent weight flow, brake internal efficiency, equivalent total-pressure ratio, and percentage of design equivalent rotor speed. All parameters are corrected to NACA standard sea-level conditions corresponding to 29.92 inches of mercury absolute and 518.7° R. The parameters were reduced to equivalent conditions in the same manner as in reference 1.

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The variation of equivalent shaft work $E/\theta_{cr,0}$ with a weight-flow parameter $\frac{wN}{60\delta_0}\varepsilon$ for constant values of over-all total-pressure ratio $p_0'/p_{x,7}'$ and equivalent rotor speed $N/\sqrt{\theta_{cr,0}}$ is presented in figure 3. Contours of constant values of brake internal efficiency η_i are included. The turbine design operating point based on the design equivalent speed and the design equivalent work output is shown. This design operating point occurs at an over-all total-pressure ratio of approximately 3.45 and corresponds to a brake internal efficiency of 0.877. Peak efficiency at the design equivalent speed was 0.878, occurring at an over-all total-pressure ratio of 3.2. Values of efficiency greater than 0.88 were obtained at overspeed turbine operation. The maximum efficiency obtained was 0.886 and occurred at a pressure ratio of 4.0 and 120 percent of the design equivalent rotor speed. It can be noted further in figure 3 that the turbine yields a comparatively high efficiency over a wide range of pressure ratio and speed. The turbine exhibits higher peak efficiencies and a wider range of efficient operation than were attained by the two turbines reported in references 1 and 5, although all three units were designed to produce essentially the same work output. The J71 experimental turbine, therefore, has adequate flexibility to allow for the previously mentioned different modes of engine operation.

The variation of equivalent weight flow $\left(w\sqrt{\theta_{cr,0}}/\delta_0\right)\varepsilon$ with over-all total-pressure ratio is presented in figure 4. The figure indicates that, above an over-all pressure ratio of approximately 4.1, the turbine is choked for all values of equivalent speed. The value of choking weight flow decreases as the turbine speed is increased. It appears that the weight-flow curves for the 60-, 70-, 80-, and 90-percent speeds would all choke at a value of approximately 42.95 pounds per second if higher pressure ratios were obtainable, indicating that in this speed range the first stator is probably choked. Because of the decrease in equivalent weight flow with increases in rotational speeds above 90 percent of design equivalent speed and at pressure ratios above 4.1, it is concluded that the turbine does not choke in the first stator, but somewhere downstream of the first stator.

As stated previously, the design equivalent weight flow was 40.3 pounds per second. Furthermore, the design equivalent shaft work was obtained at an over-all pressure ratio of 3.45, as denoted in figure 3. At the design speed and at a pressure ratio of 3.45, the observed weight flow from figure 4 was 42.44 pounds per second, or 5 percent more than the design value, even though the stator areas were decreased to 97 percent of the design value.

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Figure 5 presents the variation of equivalent torque $\frac{\tau}{\delta_0}\varepsilon$ with over-all total-pressure ratio for the various equivalent rotor speeds investigated. For the range of conditions investigated, it can be noted that the values of equivalent torque are still increasing at the high pressure ratios. The slopes of these curves for the higher speeds are decreasing, however, as the pressure ratio is increased. This indicates that limiting blade loading, defined herein as the point at which any increase in pressure ratio at any given speed results in no increase in work output (or equivalent torque), in the last rotor was not reached, although it was being approached. The mechanism of turbine limiting blade loading is discussed and analyzed in reference 6.

Blade-Row Choking

Figure 6 is a plot showing the variation of the ratio of the static pressure at the hub of the turbine to the inlet pressure p/p_0' as a function of the over-all pressure ratio $p_0'/p_{x,7}'$, as observed at the different measuring stations for the design equivalent rotor speed. Curves of this type have proved useful in determining which blade rows in a turbine are choked, if any, and the turbine operating condition at which these blade rows choke. Choking in a particular blade row, or downstream of a blade row, is prevalent when the ratio of static pressure to inlet total pressure ahead of the blade row remains constant with increasing values of over-all turbine pressure ratio. Choking in a given blade row, rather than some point downstream, occurs if the pressure-ratio curve ahead of the particular blade row obtains a zero slope at a lower over-all pressure ratio than those curves representing measuring stations farther downstream.

Figure 6 indicates that all measuring stations have a zero slope at a pressure ratio of approximately 4.2, with the exception of measuring stations 7 and 8. The fact that the ordinate continuously decreases for these two measuring stations as the over-all pressure ratio is increased above this value of 4.2, while the preceding measuring station (station 6) remains constant, denotes that the third-rotor row of blades is operating at a choked condition. This choking value of pressure ratio at the design speed is well above the design operating pressure ratio (3.45) as indicated in figure 3. At pressure ratios above this choking value of 4.2, then, any additional work output from the turbine must result solely from an increase in the tangential velocity out of the third rotor. No choking was observed in the turbine tailcone.

Because all curves ahead of station 6 in figure 6 attain a zero slope at about the same pressure ratio (4.2), it is difficult to ascertain whether any of the preceding blade rows are also choked. However, it can be concluded that the first stator is unchoked, because the value of p/p_0' behind the stator (measuring station 2) did not reach the choking value of 0.528. Figure 6 also indicates that at measuring station 1 (ahead of first stator) the value of p/p_0' is constant at a value of 0.92 over most of the range of pressure ratio investigated. This value is actually, then, a measure of the free-stream velocity pressure at the hub of the first-stator entrance and is relatively constant solely because the air-flow change over the entire range of pressure ratios investigated was only 18 percent.

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SUMMARY OF RESULTS

From an investigation of a J71 experimental three-stage turbine with 97-percent-design stator areas operated over a range of equivalent speed and total-pressure ratio at inlet conditions of 35 inches of mercury absolute and 700° R, the following results were obtained:

1. At the design equivalent speed and shaft work output of 32.4 Btu per pound, the turbine produced a brake internal efficiency of 0.877 at an over-all total-pressure ratio of 3.45.

2. The maximum brake internal efficiency obtained was 0.886 and occurred at a pressure ratio of 4.0 and 120 percent of design equivalent rotor speed.

3. The turbine presented a wide range of efficient operation, thereby permitting flexibility of engine operation.

4. The equivalent weight flow obtained at the equivalent design speed and work output was 42.44 pounds per second, or approximately 105 percent of the design value.

5. Limiting blade loading of the third-stage rotor was being approached, but was not obtained over the range of conditions investigated.

6. The third rotor choked at design speed and an over-all pressure ratio of 4.2.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 19, 1954

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TABLE I. - DATA SUMMARY FROM INVESTIGATION OF J71

EXPERIMENTAL TURBINE

Calculated over-all total-pressure ratio, $p_0'/p_{x,7}'$	Over-all total-pressure ratio, p_0'/p_7'	Inlet total pressure, p_0', in. Hg abs	Inlet total temperature, T_0', °R	Outlet total temperature, T_7', °R	Turbine speed, N, rpm	Weight flow, w, lb/sec	Torque, τ, ft-lb
1.351	1.341	34.96	701.1	672.7	705	36.06	2694
1.363	1.362	34.96	702.1	657.0	1406	35.19	2034
1.370	1.361	34.87	701.9	652.6	2116	33.63	1407
1.516	1.502	34.93	701.2	666.0	707	38.86	3519
1.530	1.526	34.87	701.2	644.3	1402	38.75	2865
1.538	1.532	34.89	701.1	635.8	2104	37.53	2144
1.528	1.513	34.91	701.1	636.8	2462	36.45	1759
1.528	1.502	34.94	701.1	635.5	2820	36.29	1512
1.522	1.479	34.98	701.1	640.8	3164	35.59	1220
1.521	1.471	35.02	701.1	645.0	3514	35.40	1005
1.514	1.454	34.99	701.1	651.1	3876	35.12	791
1.704	1.679	34.98	701.4	659.4	709	40.49	4197
1.694	1.662	34.83	701.3	661.0	706	40.37	4189
1.717	1.716	34.99	701.4	632.8	1408	40.65	3520
1.711	1.702	34.88	701.3	635.0	1409	40.49	3513
1.737	1.728	34.85	701.3	619.5	2108	39.76	2820
1.750	1.736	34.92	701.3	616.0	2444	39.58	2507
1.731	1.725	34.97	701.4	615.3	2462	39.40	2412
1.764	1.741	34.96	701.3	614.6	2815	39.09	2194
1.737	1.715	34.91	701.2	614.6	2814	38.86	2104
1.772	1.735	34.81	701.2	613.8	3160	38.65	1924
1.776	1.722	34.92	701.2	616.0	3524	38.28	1649
1.738	1.686	34.83	701.2	618.5	3506	38.25	1585
1.772	1.696	34.89	701.2	620.9	3862	38.13	1412
1.998	1.963	34.83	701.4	622.6	1402	41.82	4289
1.985	1.950	34.66	701.2	622.2	1406	42.04	4283
2.017	1.998	34.73	701.4	602.9	2110	41.46	3552
2.029	2.014	34.78	701.3	597.3	2460	41.23	3200
2.028	2.021	34.84	701.4	594.9	2470	41.40	3182
2.040	2.016	34.86	701.3	593.4	2816	40.84	2854
2.048	2.014	34.90	701.3	592.4	3169	40.47	2535
2.054	2.006	34.86	701.3	592.7	3519	40.07	2231
2.050	1.982	34.94	701.3	594.9	3870	39.84	1978
2.046	1.949	34.96	701.3	599.7	4220	39.58	1709
2.040	1.920	34.99	701.3	606.5	4578	39.46	1461
2.194	2.178	34.82	701.4	596.5	2112	42.21	3952
2.247	2.228	34.92	701.3	584.4	2460	41.95	3603
2.218	2.199	34.83	701.3	586.5	2460	42.05	3595
2.269	2.243	34.83	701.3	578.9	2812	41.56	3277
2.248	2.224	34.80	701.3	581.0	2810	41.55	3248
2.293	2.262	34.95	701.4	577.0	3166	41.22	2935
2.254	2.226	34.83	701.3	579.1	3166	41.21	2908
2.291	2.248	34.87	701.3	576.1	3516	40.92	2648
2.261	2.213	34.86	701.3	578.2	3516	40.86	2589
2.263	2.195	34.88	700.3	579.5	3865	40.58	2309
2.240	2.175	34.86	701.3	580.4	3880	40.57	2275
2.240	2.156	34.92	701.3	582.5	4226	40.28	2022
2.256	2.166	34.81	701.3	582.7	4228	40.24	2001
2.247	2.126	34.97	701.3	588.6	4566	40.28	1792
2.234	2.108	35.03	701.3	589.5	4574	40.23	1763

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TABLE I. - Concluded. DATA SUMMARY FROM INVESTIGATION OF J71 EXPERIMENTAL TURBINE

Calculated over-all total-pressure ratio, $p_0'/p_{x,7}'$	Over-all total-pressure ratio, p_0'/p_7'	Inlet total pressure, p_0', in. Hg abs	Inlet total temperature, T_0', $^{\circ}R$	Outlet total temperature, T_7', $^{\circ}R$	Turbine speed, N, rpm	Weight flow, w, lb/sec	Torque, τ, ft-lb
2.585	2.560	34.92	701.4	576.5	2112	42.84	4568
2.597	2.557	34.83	701.5	569.1	2462	42.66	4201
2.588	2.542	35.10	701.5	570.6	2461	42.55	4149
2.618	2.583	34.77	701.4	563.0	2809	42.33	3834
2.618	2.600	34.79	701.4	562.3	2818	42.22	3813
2.632	2.591	34.90	701.4	559.1	3151	42.16	3477
2.645	2.612	34.92	701.4	557.9	3168	42.03	3466
2.639	2.596	34.81	701.3	556.0	3523	41.73	3115
2.604	2.558	34.76	701.3	558.0	3503	41.60	3070
2.639	2.594	34.86	701.3	557.1	3870	41.45	2812
2.630	2.573	34.79	701.3	556.6	3848	41.31	2807
2.634	2.551	34.79	701.3	558.8	4216	41.16	2537
2.621	2.525	34.97	701.3	559.5	4222	41.19	2498
2.638	2.525	34.82	701.3	560.6	4571	41.04	2285
2.966	2.887	34.85	701.4	566.4	2106	43.07	5019
2.997	2.999	34.82	701.4	555.8	2458	42.92	4662
3.018	2.959	34.83	701.4	547.1	2818	42.80	4326
3.044	2.984	34.79	702.4	542.1	3168	42.51	3953
3.053	3.013	34.83	701.4	538.4	3500	42.26	3618
3.063	2.995	34.86	701.4	537.1	3867	41.90	3235
3.077	3.010	34.83	701.3	537.5	4213	41.61	2928
3.043	2.923	34.87	701.3	539.9	4582	41.54	2655
3.306	3.245	34.85	701.4	545.5	2451	42.98	4970
3.275	3.218	34.85	701.5	547.0	2460	42.90	4936
3.306	3.238	34.91	702.4	537.0	2802	42.91	4596
3.316	3.288	34.72	701.4	536.8	2822	42.77	4580
3.352	3.210	34.76	701.4	530.3	3169	42.52	4272
3.350	3.219	34.77	702.3	530.8	3164	42.61	4221
3.406	3.376	34.81	701.4	526.3	3516	42.31	3955
3.387	3.361	34.82	701.4	526.2	3520	42.27	3869
3.375	3.304	34.86	700.3	523.4	3868	42.08	3511
3.428	3.339	34.86	702.3	523.5	4220	41.76	3225
3.330	3.349	34.93	701.3	527.3	4571	41.67	2890
3.976	3.915	35.74	701.3	513.9	3171	44.11	4777
4.049	3.865	35.79	701.3	507.7	3518	43.84	4448
4.091	3.909	35.85	701.3	505.2	3875	43.65	4096
4.124	4.051	35.73	702.3	504.4	4224	43.18	3762
4.150	4.055	35.81	701.3	503.5	4572	43.21	3476
4.288	4.187	35.76	701.3	510.3	3164	44.13	4915
4.391	4.184	35.73	702.3	503.9	3518	43.76	4558
4.224	4.072	35.02	701.3	502.4	3516	42.70	4387
4.321	4.074	35.65	701.3	501.2	3872	43.54	4190
4.416	4.230	35.74	701.3	499.7	4221	43.19	3883
4.391	4.217	35.68	701.3	500.6	4235	43.14	3861
4.428	4.456	35.78	701.3	499.1	4576	43.15	3608
4.671	4.327	35.74	702.3	506.2	3170	44.05	5068
4.765	4.565	35.93	702.3	501.0	3524	44.00	4733
4.820	4.641	34.90	701.4	494.9	3517	42.59	4612
4.901	4.590	35.80	701.3	496.4	3873	43.54	4375
4.989	4.369	35.78	701.3	496.6	4218	43.33	4071
4.936	4.864	35.70	701.3	495.8	4575	43.05	3753

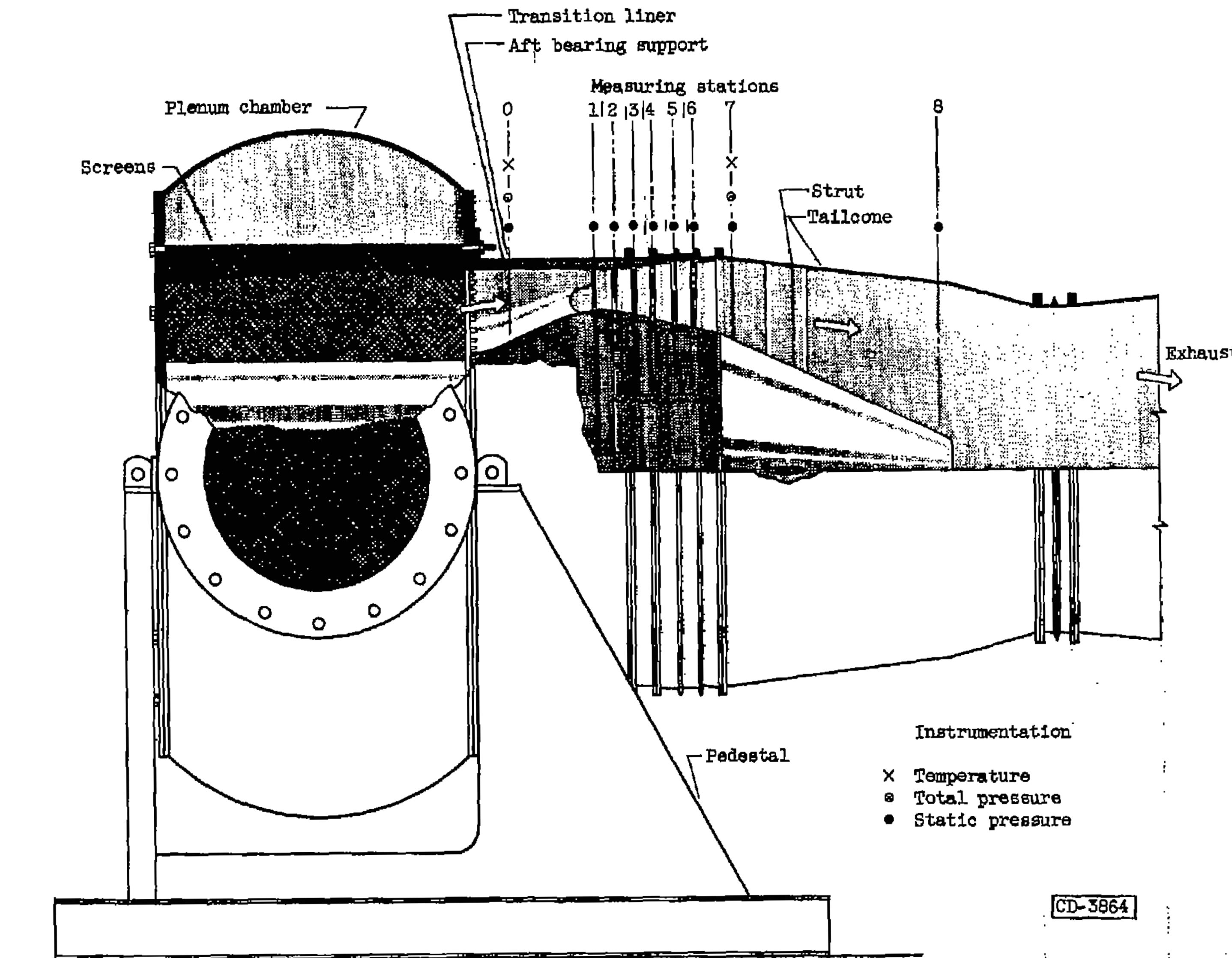

Figure 1. - Schematic diagram of J71 experimental turbine assembly and instrumentation.

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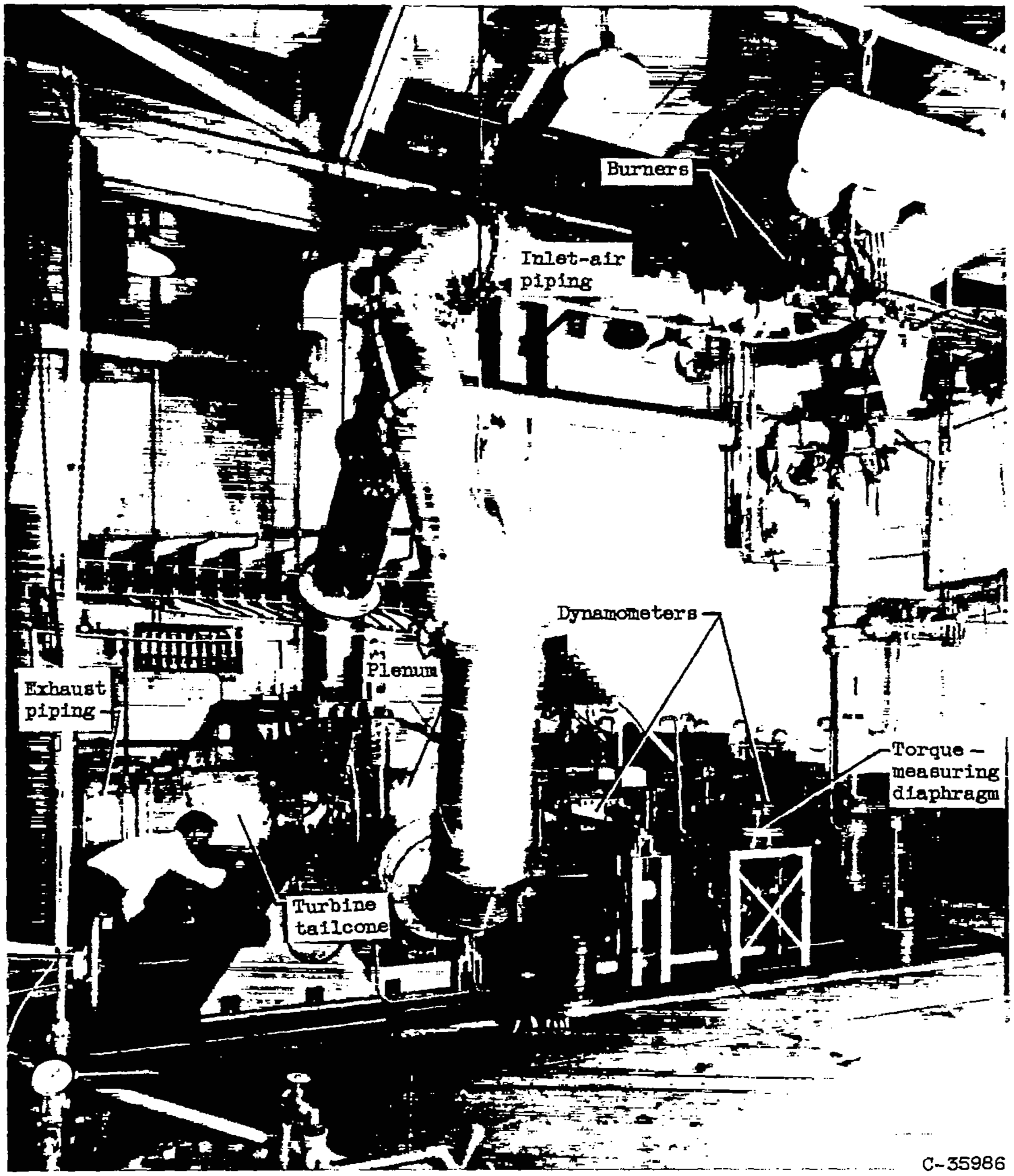

Figure 2. - Installation of J71 experimental three-stage turbine on full-scale turbine component test facility.

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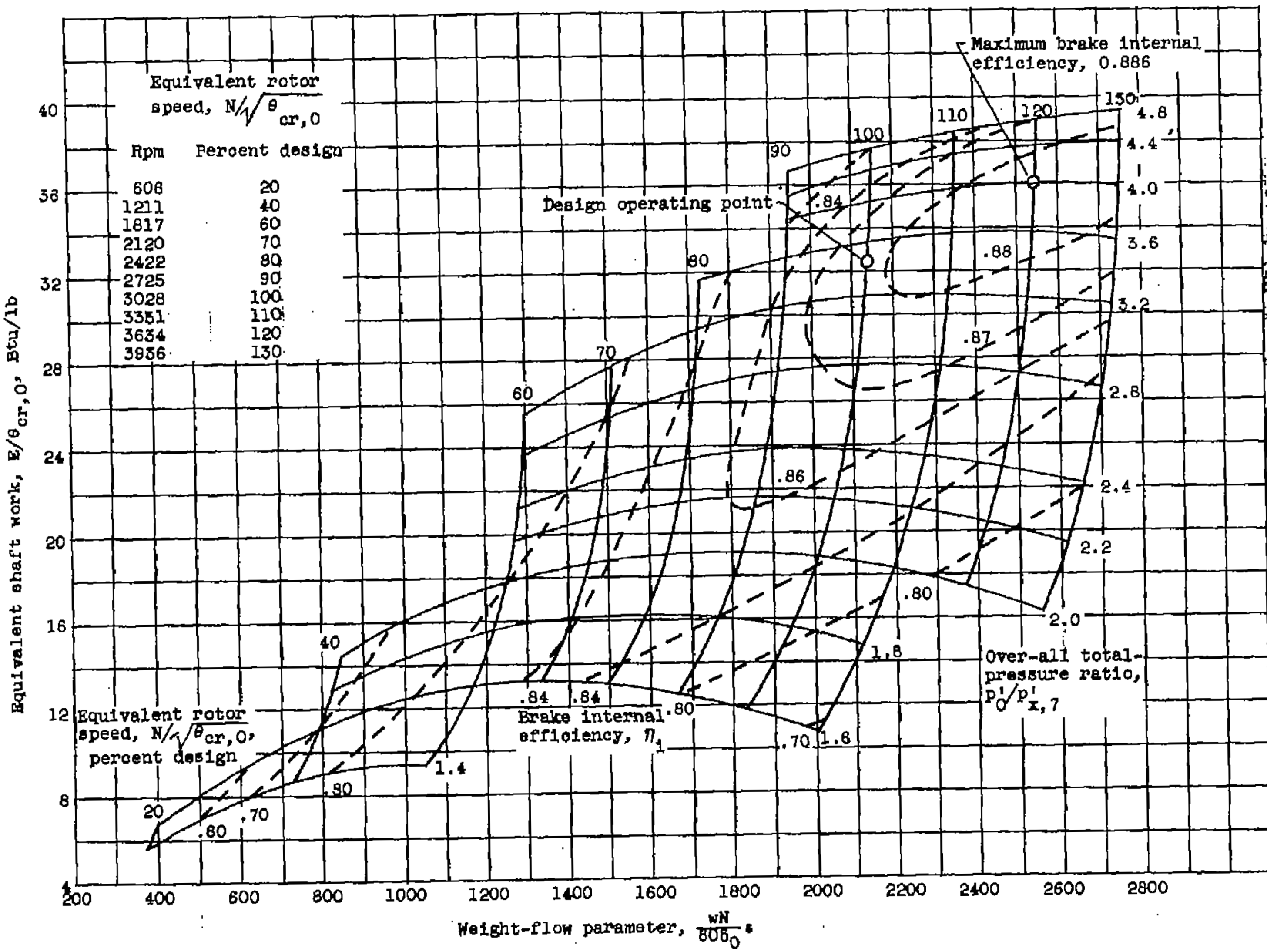

Figure 3. - Over-all performance of J71 experimental three-stage turbine. Turbine-inlet pressure, 35 inches of mercury absolute; turbine-inlet temperature, 700° R.

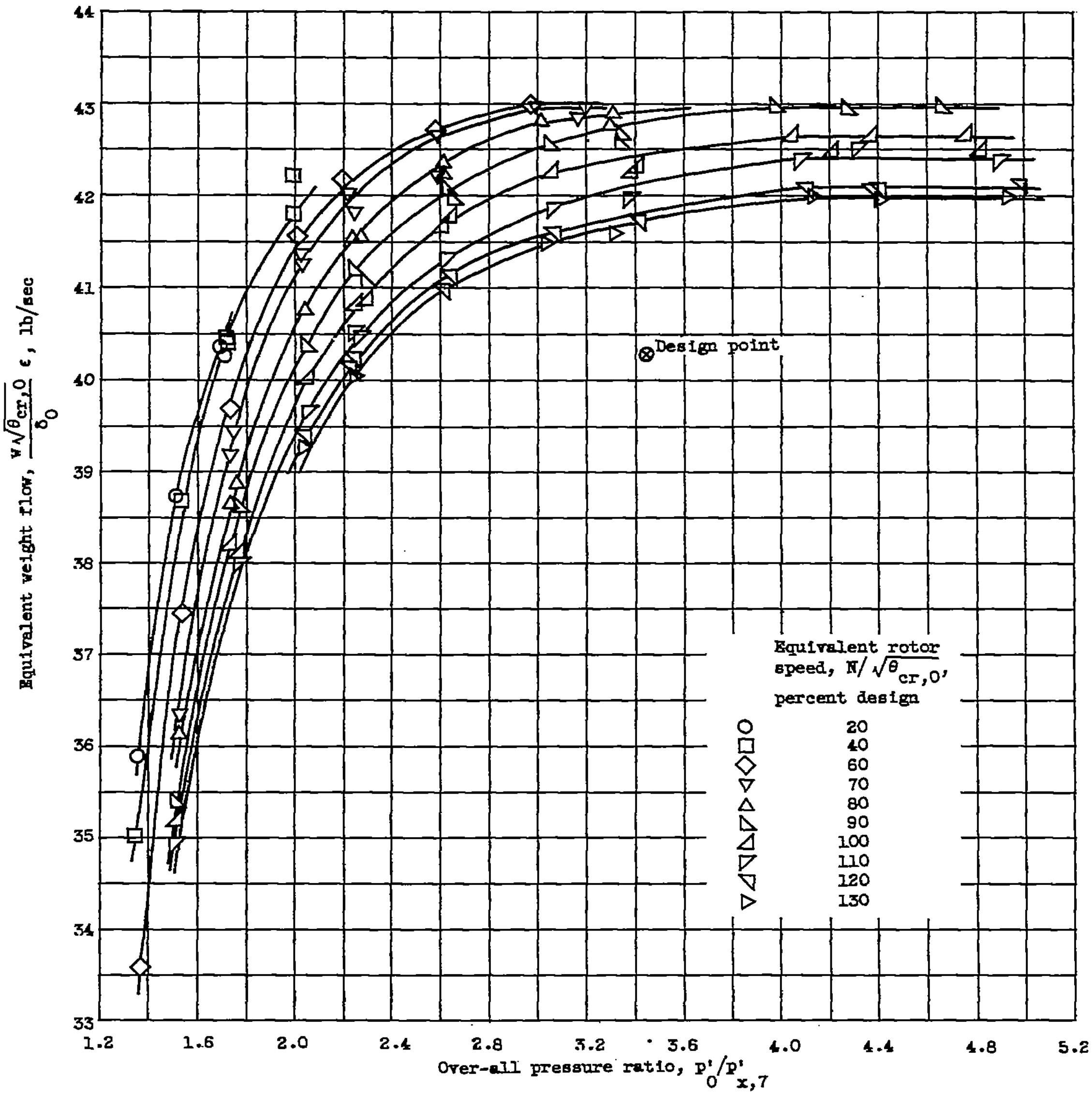

Figure 4. - Variation of equivalent weight flow with over-all pressure ratio for constant values of equivalent rotor speed.

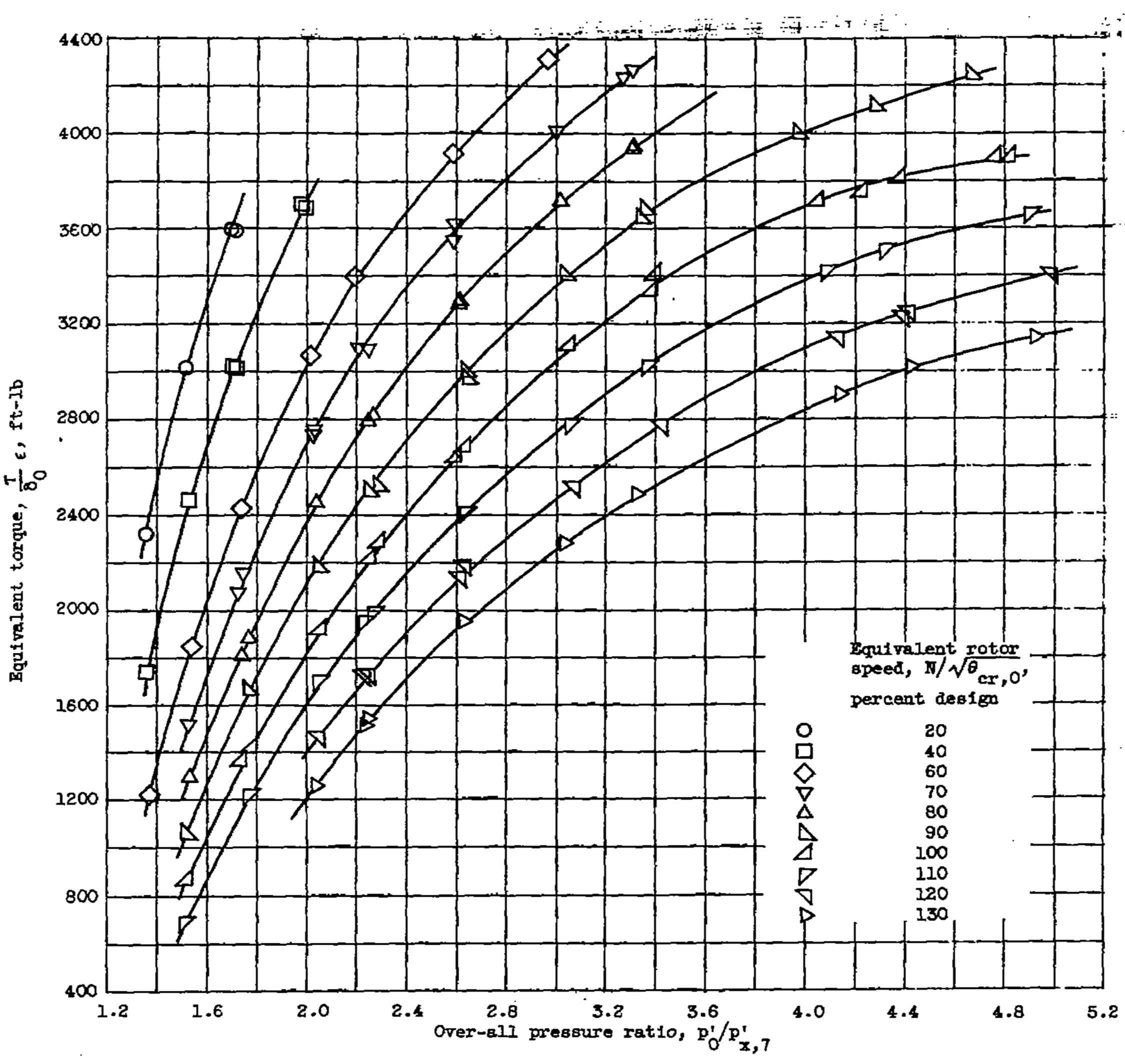

Figure 5. - Variation of equivalent torque with over-all pressure ratio for constant values of equivalent rotor speed.

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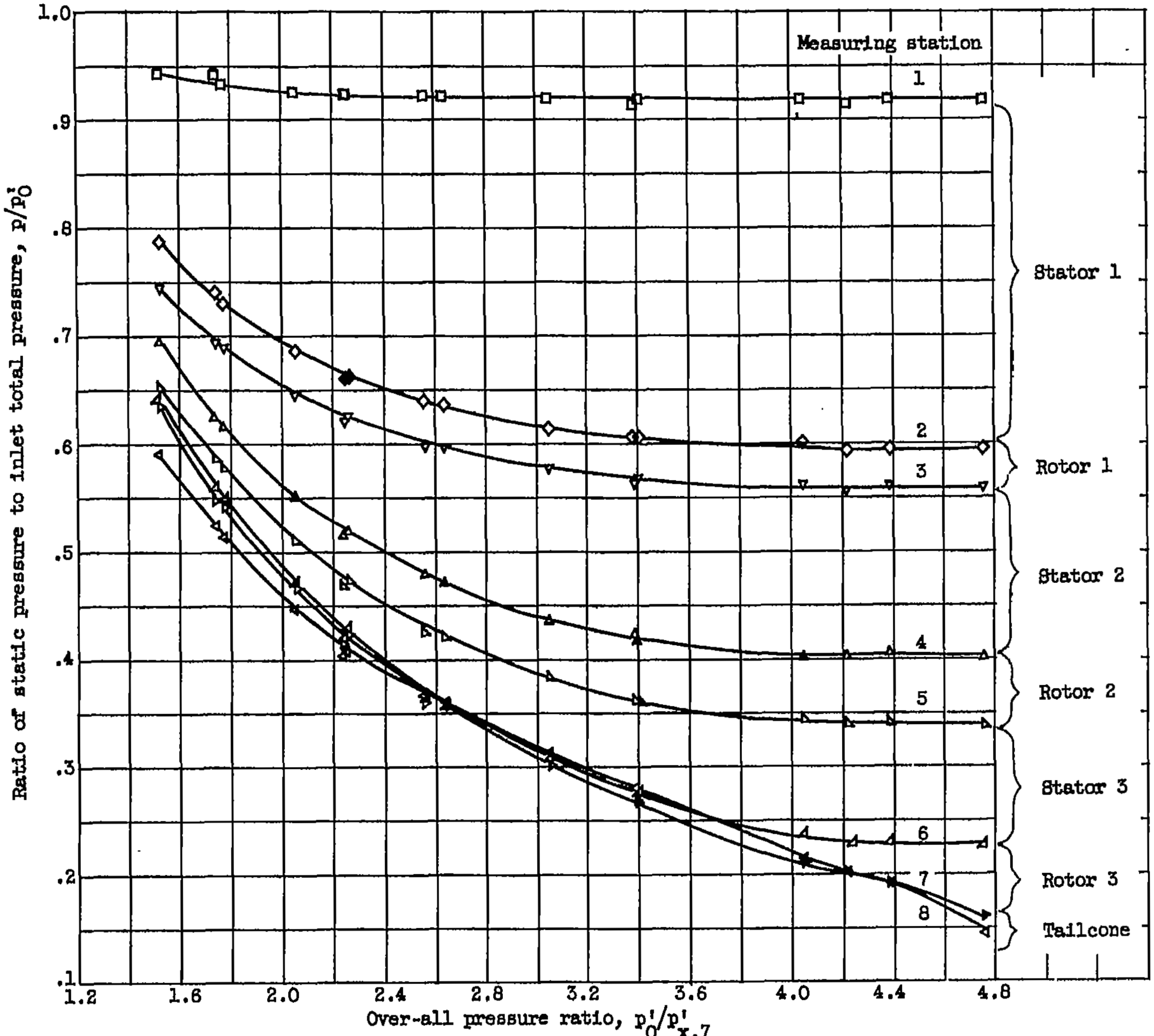

Figure 6. - Variation of ratio of hub static pressure to inlet total pressure with over-all pressure ratio at different measuring stations for design equivalent speed.

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